SOLID-STATE CONTROLLED FIRE HAZARD DETECTION AND QUENCHING SYSTEM

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ABSTRACT

This paper presents a novel scheme to detect the fire hazard in air and ground vehicle and to quench the fire in a reliable way. Microcontroller based fire hazard detection and quenching system is developed, tested and found working satisfactory. Its response is very fast to quench the fire hazard before it spreads out. It is smart to avoid any false alarming in case of momentary fire occurrence. Special emphasis has been laid down in choosing the precision amplifier for the thermocouple, digitizer, and solid-state relays, which makes the system reliable. It has built-in-test facility and any malfunction of system is indicated. It has under gone the environmental test successfully.

INTRODUCTION

There is a need to develop a substitute for the existing valve based fire hazard detection and quenching system of aircraft and ground combat vehicle. The response time of the existing systems is very high. These systems are not reliable mainly due to the use of electromechanical devices. At first, a microprocessor based fire hazard detection and quenching system [1] was developed. Presently, microprocessor is replaced with microcontroller.

The basic concept of automatic fire detection is to recognize the fire hazard before fire could spread and to give a warning signal followed by triggering the fire extinguisher by using the technical means only. Such systems already exist in industrial environments, business establishments and at residential complex. There has been considerable development in these systems due to the availability of integrated chips [2].

The automatic fire detection and extinguishing for aircraft needs to be smart, fast acting, reliable, compact and efficient. The trend towards smart fire detection and extinguishing become of paramount importance for the air and ground vehicle employed in military and civil environment. Many of the existing schemes are either electro mechanical relay or electronic valve based system. They suffer from maintenance and malfunctioning problems. The problems associated with the relay based design involve oxidation of the contacts, contact arcing yielding to the damage of contacts, additional circuits have to be designed to eliminate transients and Radio Frequency Interference (RFI) signals, which can cause problems to the operation of nearby sensitive equipment and instruments. Another problem with relays is the back e.m.f which may affect the other associated active devices. Relays with misadjusted residual gap screws may suffer contact bounce as well. The fire extinguisher unit employs a detonator to ooze out the extinguisher gas. Even if the fire is put off, the gas is still being sprayed unnecessarily and hence the design does not aim to save the gas for future fire hazard. The system has 'operation check' facility only for the thermocouple circuit, and not for the relay circuit, which makes the system unreliable. The leads of the thermocouple need to be cleaned periodically as the dust can cause loss of continuity in the circuit [3].

Earlier, analog electronic circuits were being used to detect fires. The design used was based upon hardware logic employing operational amplifiers. Although they perform well when compared to relay logic, these suffer from the drift and offset problems, which can cause malfunctioning owing to deviations in their operating characteristics. These circuits tend to become bulky, increasing the failure rate of the individual components. The design of the circuit also becomes complex owing to the fact that signal conditioning is required for the signals obtained from the transducer.

By way of avoiding the above drawbacks, initially an improved version of the fire detection and extinguishing scheme was designed based on microprocessor and sophisticated custom-built instrumentation ICs [1, 2]. Later, the scheme is further improved in terms of response time by using microncontroller in place of microprocessor.

The hardware has become more compact and reliable.

Presently, microcontrollers have been finding universal acceptance in the fire detection applications. The fire areas in military aircraft are engine bay, armament/ammunition bay, fuel tank and other special areas. In case of fire occurrence, the gradient of rise of temperature and the spread of fire varies among these fire prone areas. Thus use of microcontroller has made the system programmable to meet these variable requirements more accurately.

The software can also be updated or altered as the system performance demands change [3]. Further, the instrumentation ICs are pre- calibrated to match the characteristics of the sensors. They also include a sensor failure alarms circuit and compensation circuits that give the signal conditions of signal being sensed by the sensor.

DESIGN OF THE FIRE FIGHTING SYSTEM

Main components:

The care has been taken in selection of components and design of circuit so that the drawbacks are eliminated and the system becomes faster, compact, reliable and smart.

The smart fire-protection and extinguishing involves following key stages:

A K-type sensor, capable of sensing the normal working temperature and fire hazard temperature, is used. Four of such 'K' type sensors are placed at four fire prone areas. The output of temperature sensor is small in magnitude, and exhibit non-linearity. IC AD 595 is used, which amplifies the signal and at the same time linearizes the input/output relationship. These signals also flag the working conditions of sensor [4].

- In order to make the system to respond faster a microcontroller is used, and is judiciously programmed to make the microcontroller to act as the brain of the fire fighting system. A most popular and low cost digitizer IC is chosen with the microcontroller. Here no peripheral interface chip is required, thus the hardware becomes compact.

- The microcontroller is programmed to identify the normal working temperature and the hazard temperature. It is programmed to indicate the normal operation and gives alarm indication in the event of fire hazard by using display device.

- The microcontroller detects the fire hazard and initiates a signal to electrically operate the solenoid valve, so as to release the fire extinguisher gas to quench the fire.
- The microcontroller de-activates the solenoid valve to block the flow of extinguishers when the fire is totally extinguished.
- The microcontroller is programmed to indicate the volume of the gas present in the extinguishing cylinder.

Hardware implementation:

The hardware implementation involves two stages: detection of the fire and extinguishing the fire. In order to detect the fire a sensor is employed. For best results, a K type thermocouple, a rugged sensor, is used. The specifications of K type (chromium aluminum) are covering temperature range: - 185 to + 1216 ^{0}C and output voltage range is 5.51mV to 51.05mV.

Signal processing unit:

The output of the thermocouple is fed to a signal-processing unit, which comprises an instrument amplifier AD 595. It is pre-calibrated by laser wafer trimming to match the characteristic of K type thermocouples. It contains a complete instrumentation amplifier and a cold junction compensator. It also includes a thermocouple failure alarm circuit that activates if thermocouple leads get open/short circuited. These junctions are isothermal with the IC itself, and the ice point compensator offsets their drift voltages.

Signal digitizing Unit:

The signal-digitizing unit is responsible for converting the output of the AD 595 to a digital quantity and fed to the microcontroller for further processing and decision-making. This unit employs analog to digital converter. The two most important parameters are considered when selecting an ADC are speed and resolution. The most popular ADCs are the successive approximation type. They offer the best trade off among speed, resolution and cost.

ADC 0809 has the feature to connect 8 analog inputs, (i.e., eight points can be chosen where fire is to be detected). The output of each AD595 is connected to analog inputs of ADC 0809. The start of conversion requires a pulse, which is obtained from the microcontroller. The ADC generates an high output when it converts the analog data into digital. The digital outputs are available at $D_0 - D_7$ (eight bits). The ADC 0809 requires a clock signal that is produced by using system clock of the microcontroller. The conversion time for the ADC is 100μsec at a clock frequency of 640 kHz [6].

Microcontroller Unit:

The fire detection and extinguishing system warrant the sensing of the fire and locating the position of the fire hazard. Once it is identified it releases the gas in order to quench the fire. To achieve these operations we use a micronctroller MCS 8051. Microcontroller (MC) is basically a microprocessor with an on-chip RAM, I/O facilities, and is a subset of single chip microcomputer. Most commonly used microcontrollers are the MCS 8051 family. Microcontroller has its own interfacing (I/O) ports (P_0, P_1, P_2 and P_3), thus the external two PPIs (IC 8255) are dispensed with. The program execution does not require any external memory. By using on chip timer an appropriate delay can be programmed in actuating the solid-state relays so as to avoid false alarming in case of momentary fire occurrences.

Special features of microcontroller includes:

- The program execution from on-chip ROM rather than external memory thereby enhancing the speed of response.
- Shared data and instruction paths
- Mostly computer embedded systems use micro controllers.

In view of the superior features of microcontroller the fire fighting system is further updated by using microcontroller chip in place of microprocessor chip.

Use of solid-state relay unit:

The electromechanical relay is one of the most important interfacing devices commonly used in an analog instrumentation and control systems. Magnetic relays are cheaper but pose isolation problems of high voltages, which can destroy digital circuits. Hence in the proposed smart fire fighting system solid-state relays (SSR) units are used. Such relays operate on logic levels and also provide 100% isolation. The solid-state relays can directly be connected to 230v ac supply to operate the solenoid valve fitted in the fire extinguisher unit. Additionally, solid-state relays are controlled through software [3].

Display unit:

The display unit is designed using 7 segment display unit indicating fire hazard interms of locations of the fire hazards, temperature and number of available extinguisher along with the available volume of gas. It also indicates the state of serviceability of the system when the built-in-test is carried out. The built-in-test is periodical/routines that includes test before taking off.

Figure1 shows circuit schematic for the hardware scheme.

REALIZATION OF THE STATE OF THE SOFTWARE CONTROL

The software control is realized with the support of:

- A database available at $D_0 - D_7$ of ADC 0809 represents the temperature.
- Detection of normal working and fire hazard temperature using software logic.
- Relating analog readings to the digital value of the ADC unit, (if non-linearity exists, suitable correction is added to get a linear relationship).
- Identification of sequence of operations to be carried out in the event of fire hazard, i.e., to initiate the SSR relay that energizes solenoid valve to inject extinguisher on the fire hazard location.
- Studying the temperature that has to be monitored during extinguishing fire and to deactivate the solenoid valve, as the temperature resumes to normal values, (i.e. when the fire is totally put off).

At the same time monitoring of other channels continues.

Also I/O ports of MC are initialized and ADC routine is developed. Fig. 2 shows the flow chart for realization of which the following are considered.

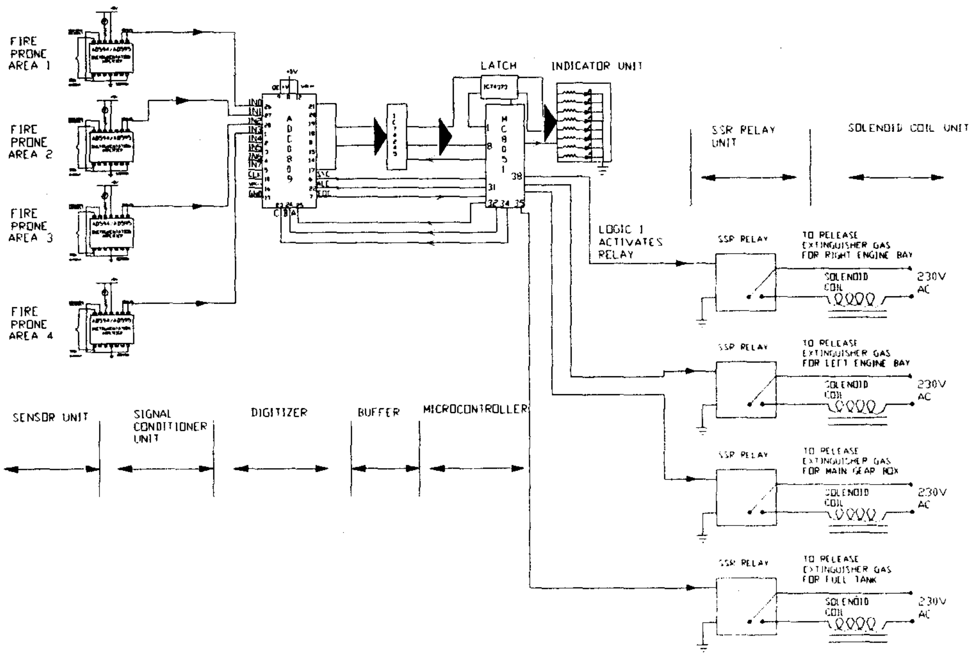

Figure 1 Circuit Diagram of Hardware

Table 1: Test Result

Condition of Operation	Temperature	Output of AD-595	Output of ADC 0809	Data Stored in RAM	Display	State of solenoid
Working temperature	200^{0}C	2.05V	01100111	-	202^{0}C	Not operated
Below Hazard Temperature	220^{0}C	2.20V	01110000		219^{0}C	Not operated
Below Hazard Temperature	240^{0}C	2.40V	01111010	-	239^{0}C	Not operated
Below Hazard Temperature	260^{0}C	2.60V	1000 0100	-	259^{0}C	Not operated
Below Hazard Temperature	280^{0}C	2.80V	10001110		278^{0}C	Not operated
Hazard Temperature set at 300^{0}C	300^{0}C	3.09V	1001 1110	1001 1110	300^{0}C	Operated
Above Hazard Temperature	350^{0}C	3.50V	10110010	-	349^{0}C	Operated
Above Hazard Temperature	400^{0}C	3.98V	11001100	-	400^{0}C	Operated
Above Hazard Temperature	500^{0}C	4.95 V	11111111	-	496^{0}C	Operated
SSR 2 Open Circuited (Testing B.I.T facility)	300^{0}C	3.09V	10011110	-	SSR 2	Not operated
SSR 2 Short Circuited (Testing B.I.T facility)	300^{0}C	3.09V	10011110	-	SSR	Not operated
Sensor1 Open Circuited (Testing B.I.T facility)	300^{0}C	-	-	-	SEN1 Flashing	Not operated
Sensor1 Short Circuited (Testing B.I.T facility)	300^{0}C	-	-	-	SEN1 Flashing	Not operated

- The normal working temperature of the engine bay is noted in ^{0}C corresponds to the output of AD595 in volts. When this is fed to the ADC0809, an equivalent digital output is generated in hex code (8-bit) giving the digital equivalent of normal working temperature of the location. This value is stored in the RAM. The hazard temperature is also simulated and its digital equivalent is stored.

- A program is developed to distinguish between normal working temperature and fire hazard temperature and to identify the different temperatures at different engine bays of the aircraft. This procedure is followed for all the channels automatically in sequence. The status of each engine bay temperature is also displayed.

- In the event of fire hazard, the logic identifies where it has taken place and the main program is routed to the quenching program.

- The fire quenching program, activates the solenoid valve corresponding to the fire prone engine bay only when the fire persistence time exceeds the set time delay, also gives fire warning indication for the pilot. Solenoid valves operate to release the fire extinguisher gas.

- Continuous monitoring of this fire prone engine bay is carried out and when the fire is totally quenched the solenoid valve is deactivated and the fire warning status is put off.

- The program resumes to normal operation mode.

TEST RESULT

The temperature range of aeroengine bay varies from 600^{0}C to 1000^{0}C depending on the type of engine and the mode of engine operation. Under normal operating condition the output of the AD595s, at the rate of 10mv/^{0}C, represent the temperature of the fire prone areas. After scaling down this output is given to ADC 0809. The 8-bit hex- output of ADC 0809 represents the digital equivalent of temperatures of the sensor locations. The simulated voltage correspond to hazard temperature is given to ADC 0809 and the output of ADC 0809 (corresponds to hazard temperature)

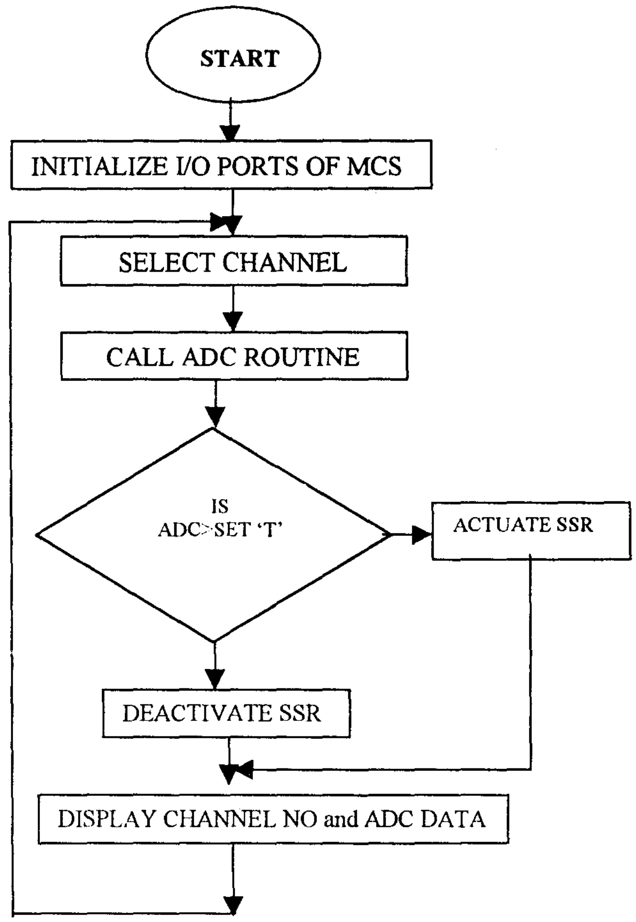

Figure 2 Flow Chart

is stored in RAM. Initial testing on the system is carried out and is shown in Table-1: It is observed that once the display shows 300^{0}C the SSR activates the solenoid.

Similarly the operation at higher temperature range is verified by appropriate scaling of input voltage to ADC 0809. It is found that solenoid gets activated and display shows 600^{0}C when the simulated voltage corresponding to 600^{0}C is given to ADC 0809. Ten hours reliability test is carried out successfully for the electronic circuit at 70^{0}C

CONCLUSIONS

The scheme has been updated by replacing microprocessor with microcontroller to make the system response faster. By replacing the microprocessor PPIs are dispensed with and the system become more compact. The false activations of fire extinguisher unit due to momentary fire occurrence is avoided. Thus the improvised scheme is made more flexible and adaptive to any other like-parameters of interest by using the same set up with minor modification in the sensor and software [7,8].

Several times the system is tested and found high consistency in its operation. An attempt can also be made to realize a black box set by interfacing different sensors and by suitably developing the software. The software can be expanded and is user friendly.

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